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# **Hardware Demonstration of the Feasibility and Value of Distributed Resources as a Solution to the Sensitive Load Problem**

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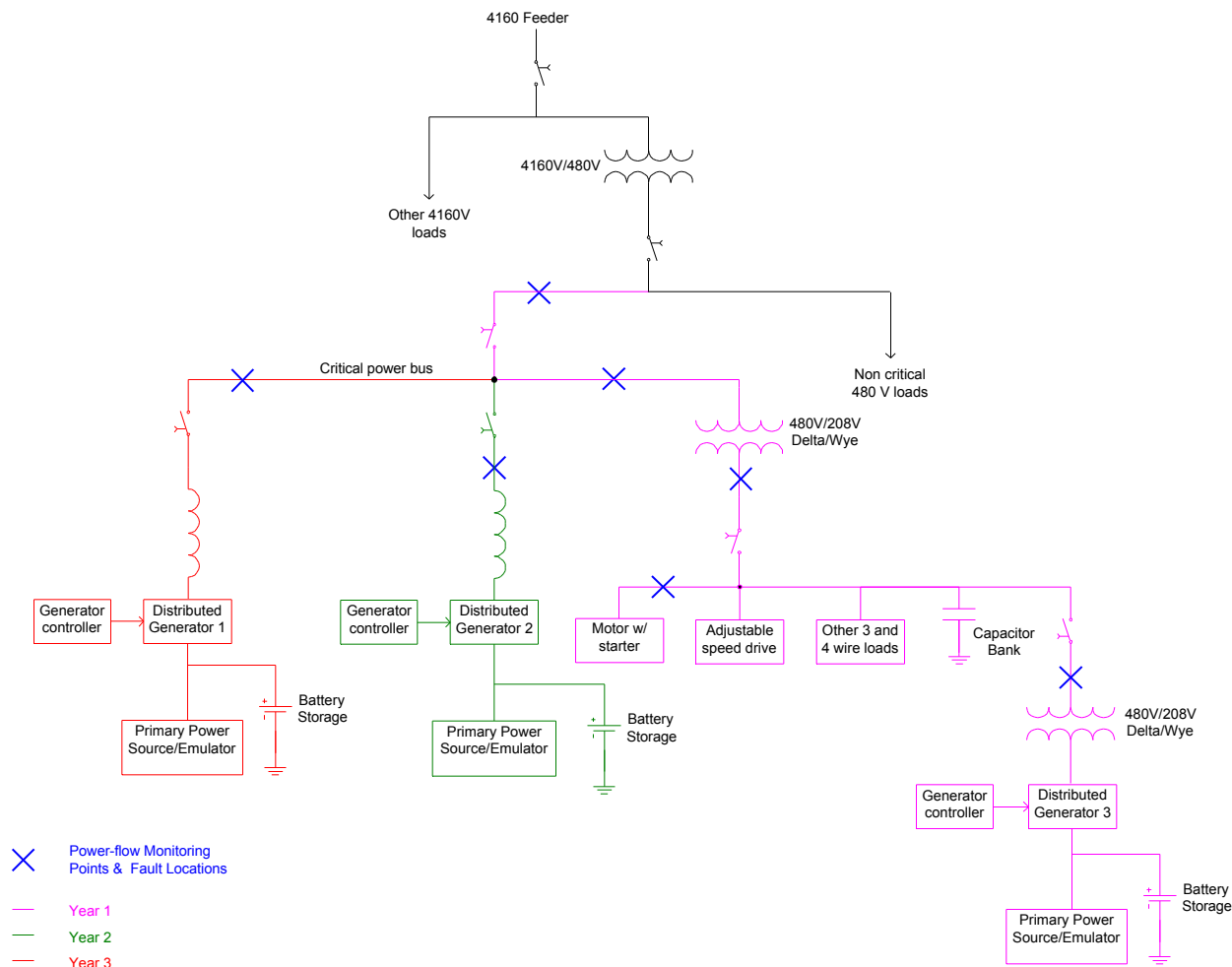
NREL, Technical Monitor

# Project Objectives

- Enable inverter based DR sources to meet demands of sensitive loads
- Enable parallel clusters of DR sources to operate in a stable manner without communication

# Proposed Hardware Platform

- Three inverters
- 3 wire and 4 wire
- Islanding and reconnection
- Direct & transformer coupling
- Complex loads
- Power source emulation
- Energy storage emulation
- Decentralized control



# Control Objectives

- Real Power-Frequency Droop Characteristics
- Reactive Power-Voltage Droop Characteristics
- Address short term power quality issues
- Ride through nominal amount of voltage sags and frequency deviations in a benign manner
- Intentionally island and feed local critical loads upon large deviation
- Reconnect upon system recovery seamlessly

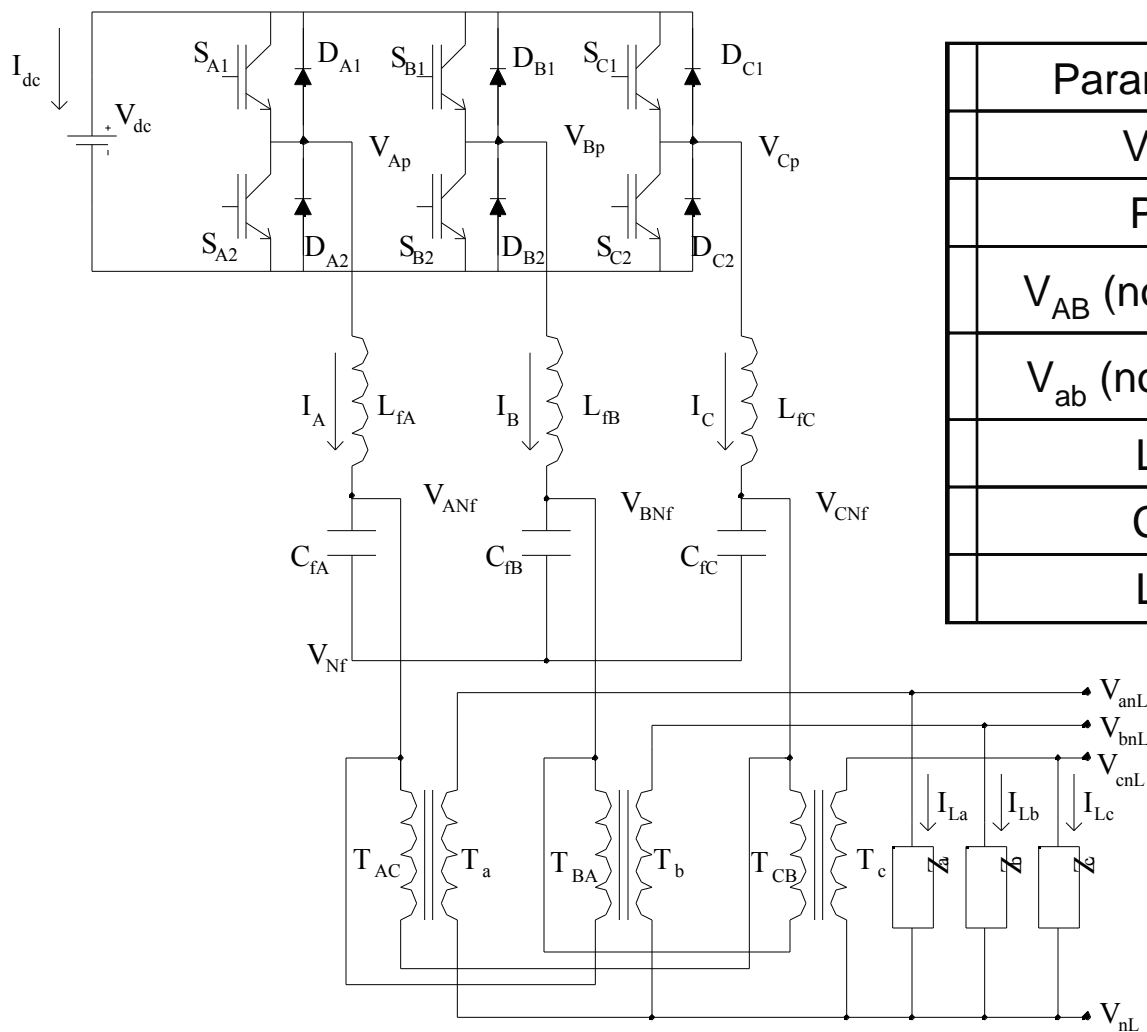
# Year 1 Tasks

- Development of Power Source Emulator
- Study of Energy Storage Requirements
- Demonstration of Operation of Single Inverter
- Development of Inverter with Distributed Generation Control Interface
- Computer Simulation Support

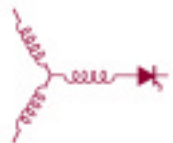
# Hardware



# Hardware features

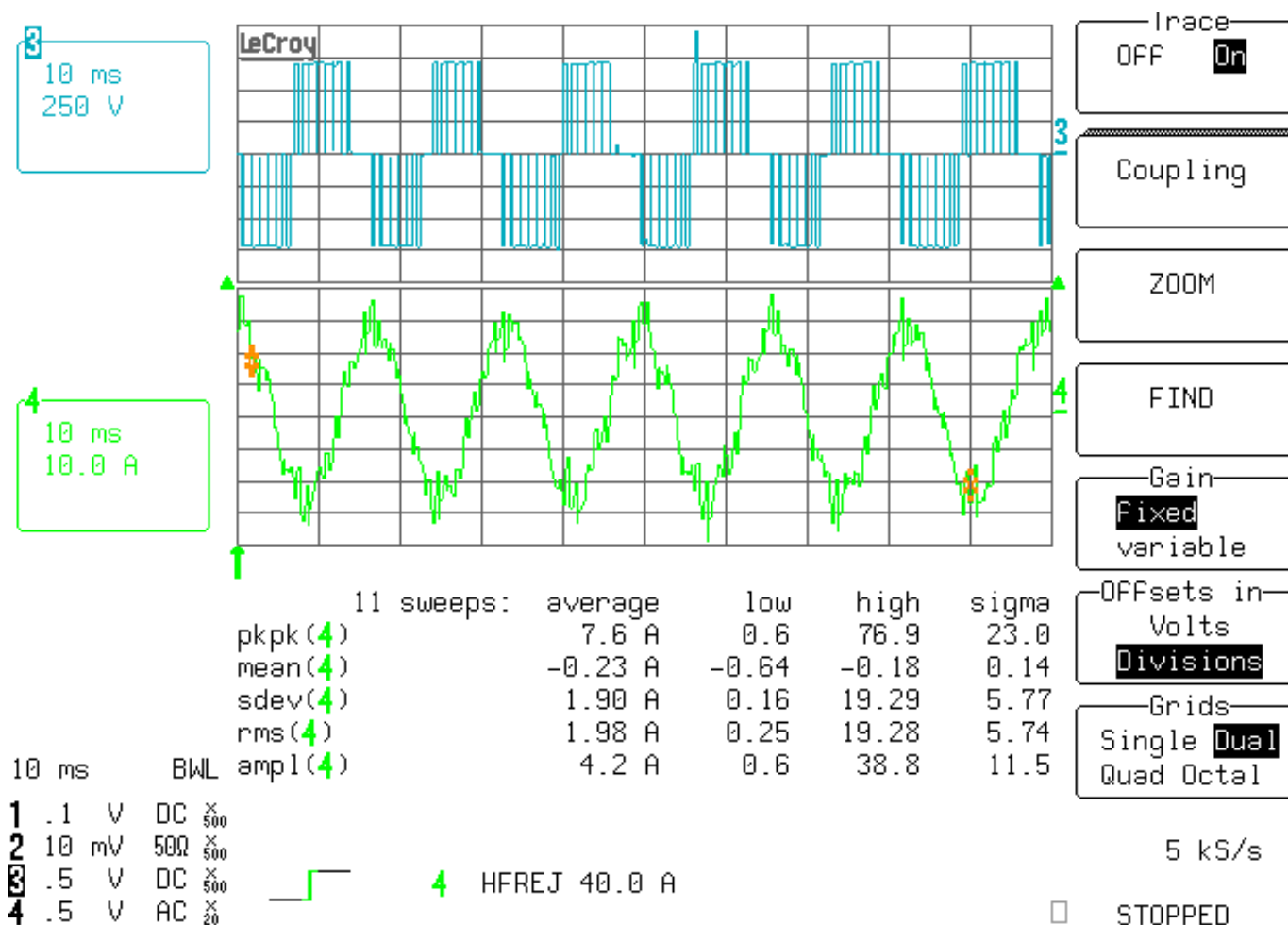


Parameter	Value
$V_{dc}$	750 V
$P_o$	15 kW
$V_{AB}$ (nominal)	480 V
$V_{ab}$ (nominal)	208 V
$L_f$	0.97 mH
$C_f$	180 $\mu$ F
$L_t$	2.1 mH



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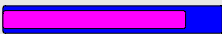



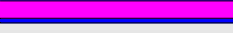




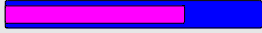





# Hardware Waveforms



## Year 2 Tasks

- Expansion of lab scale microgrid
- Modification of second inverter and power source emulator
- Demonstration of islanding and reconnection transients
- Demonstration of power quality solutions
- Computer simulation support

# Year 2 Tasks

ID	Task Name	2001				2002				2003				2004
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
1	Development of power source emulator													
2	Study of energy storage requirements													
3	Demonstration of single inverter system													
4	Development of DG control interface for inverter													
5	Computer simulation for Tasks 1-4													
6	Expansion of lab scale microgrid for utility interface and two inverters													
7	Development of second PSE and inverter													
8	Demonstration of islanding and reconnection													
9	Demonstration of two inverters power quality transients													
10	Computer simulation for Tasks 6-9													
11	Expansion of lab scale microgrid to accomodate third inverter													
12	Development of third PSE and inverter													
13	Demonstration of 3 inverters with decentralized control													
14	Demonstration of correction of common power quality problems													
15	Computer simulation for Tasks 11-15													

# Year 2 Tasks

## 6. Expansion of lab scale microgrid

Transformers – acquired

Switchgear – acquired

Cabling – acquired

Static switch – No convenient and inexpensive  
COTS – custom device under development

Wiring to be done

## Year 2 Tasks

### 7. Modification of second inverter and power source emulator

Power source emulator – Home built not convenient enough – Commercial devices have been acquired

Second inverter modification – power circuit completed and tested – Draft report delivered

DSP controllers being integrated



# Year 2 Tasks

8. Demonstration of two inverters with islanding and reconnection transients

DSP control software to be implemented

# Year 2 Tasks

## 9. Demonstration of power quality solution

DSP control software to be implemented

Means of generating power quality events to be determined

Acquiring Yokagawa powerscope



# Year 2 Tasks

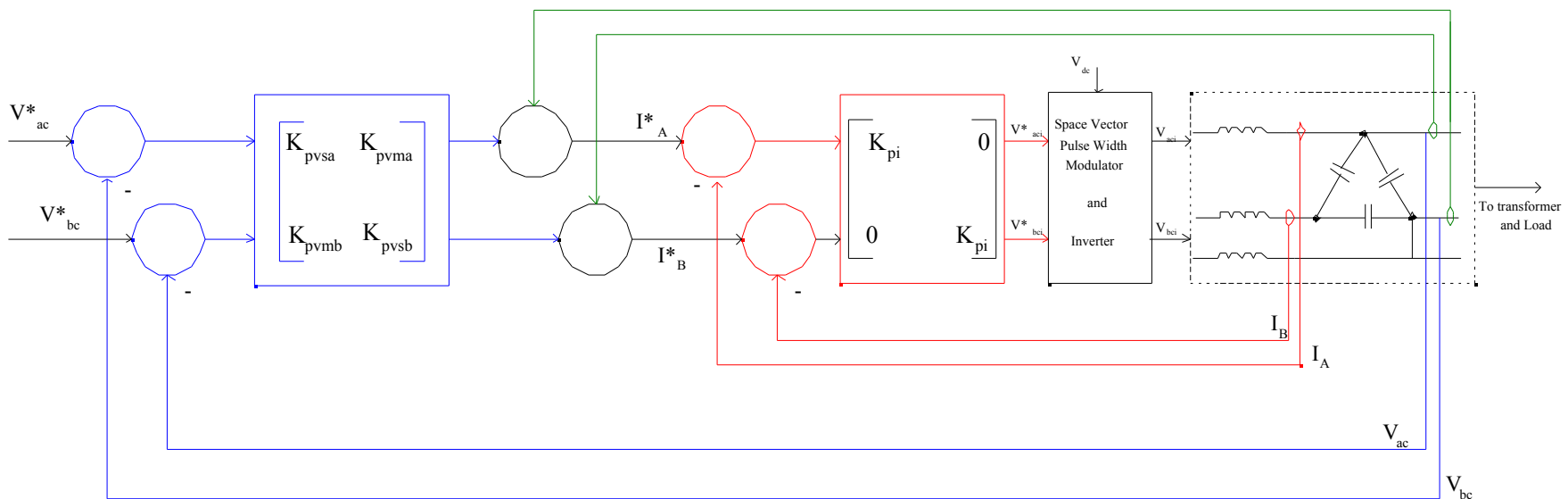
## 9. Computer simulation support for Tasks 6-9

Inverter controls development

Laboratory microgrid dynamics being simulated



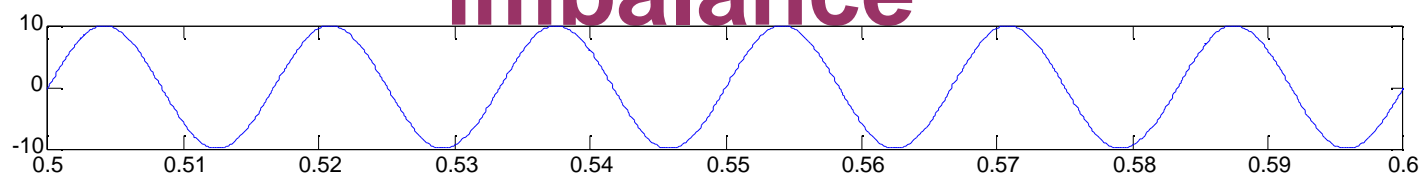
# Inverter Internal Control architecture





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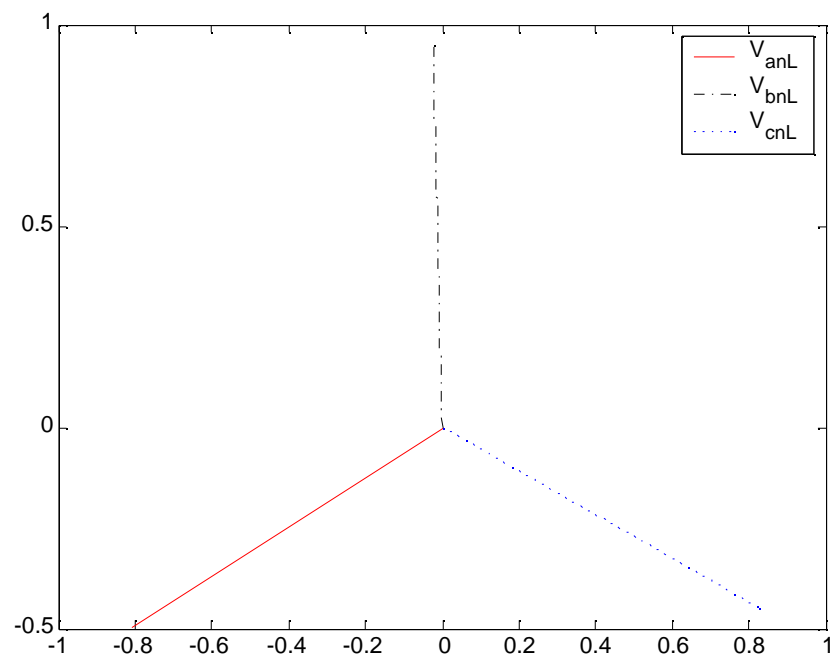
# Simulation results – load imbalance





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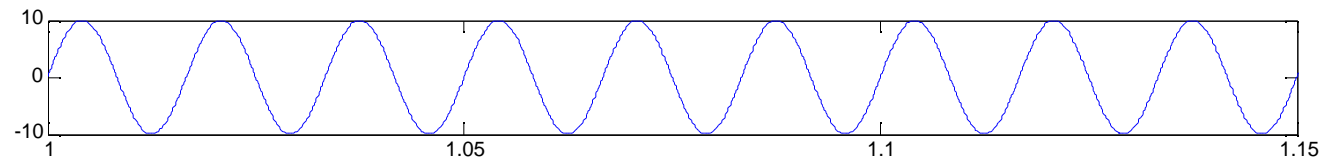
# Operation under imbalance – closed loop





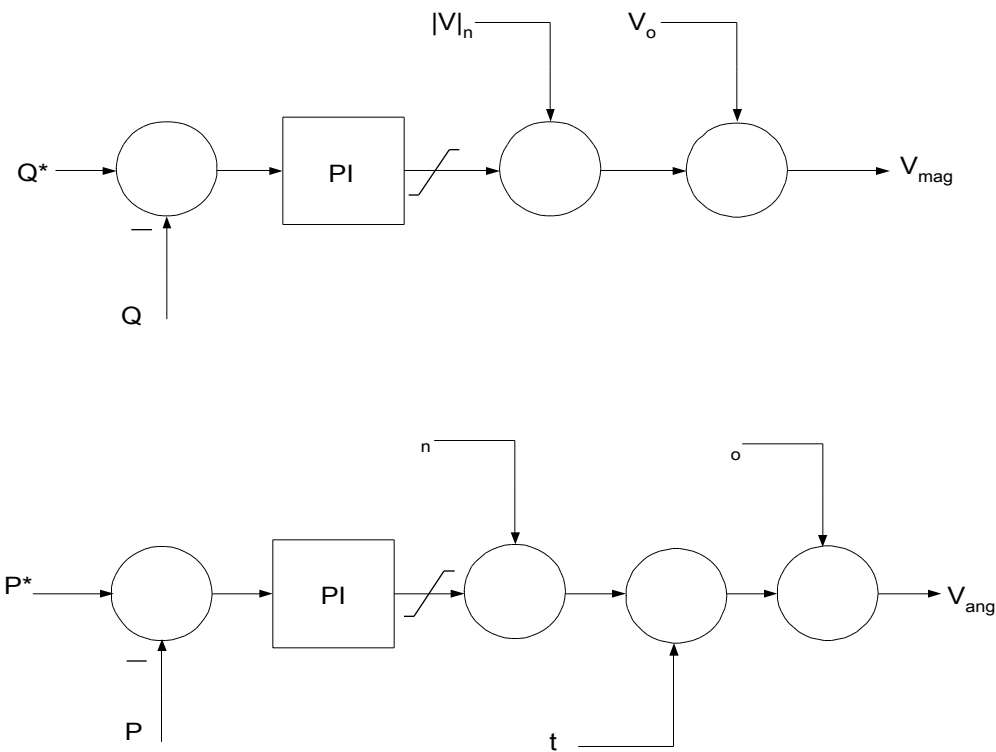
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# Simulation results – harmonic injection

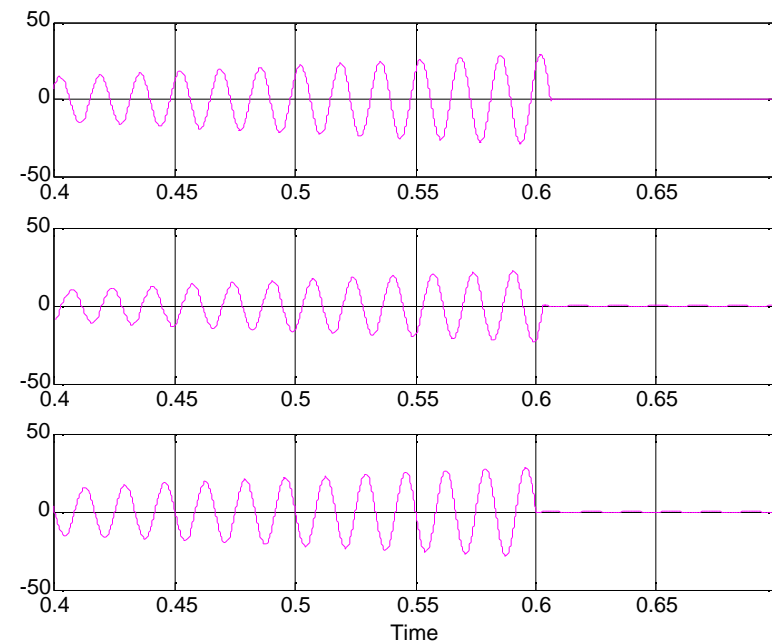
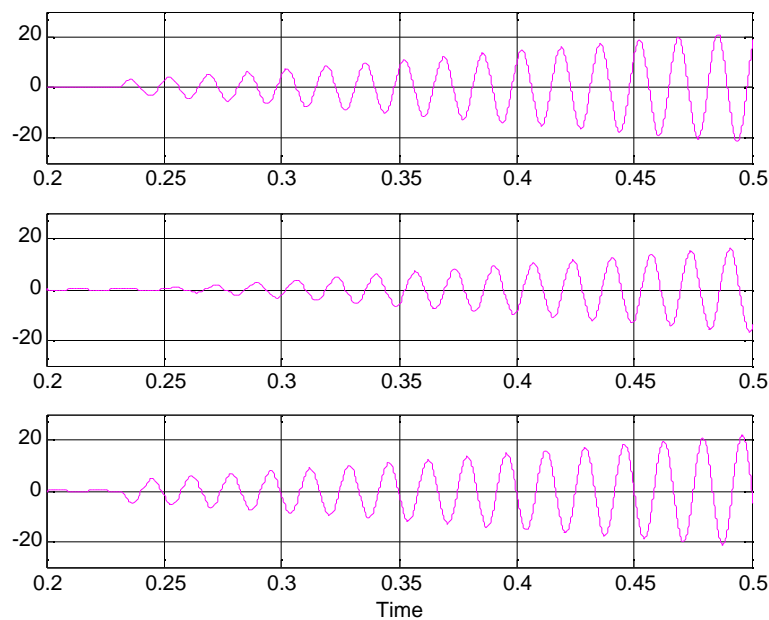




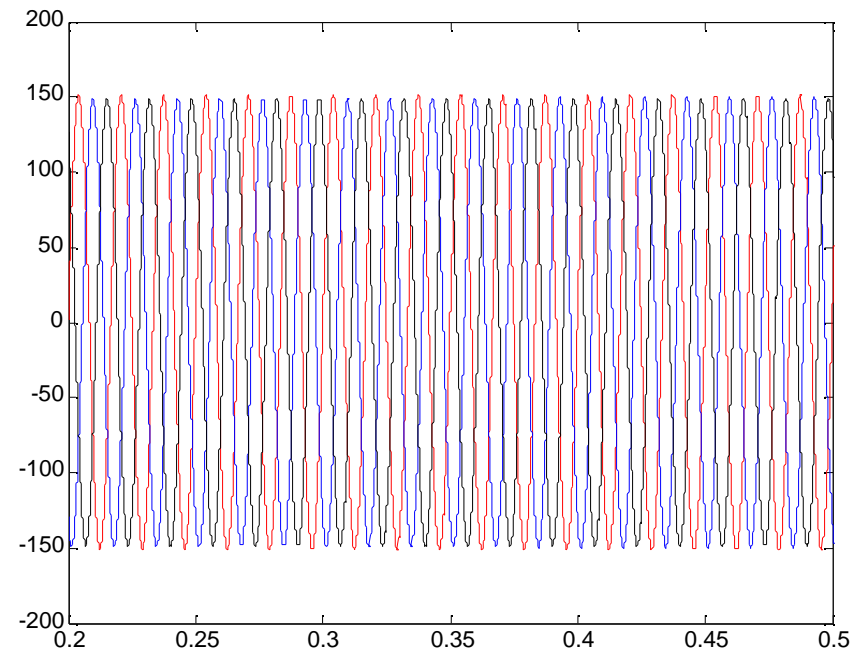
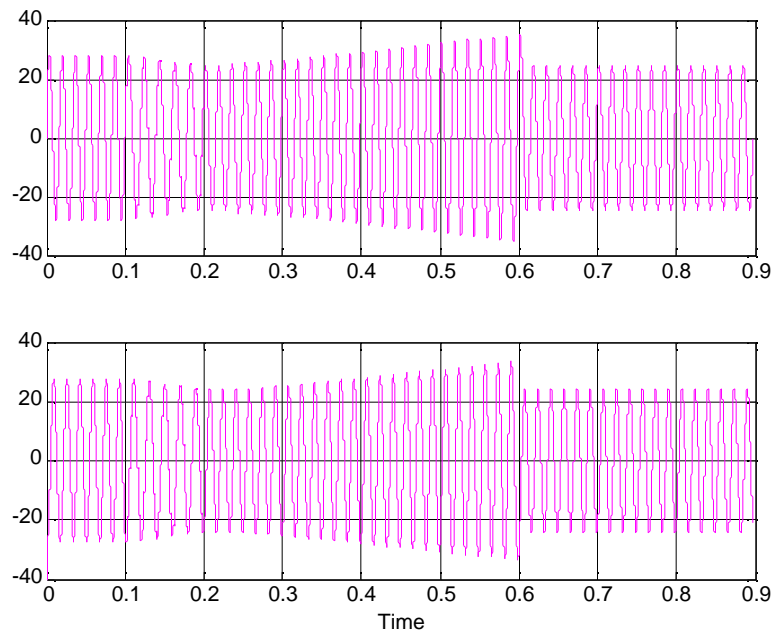
# Outer P and Q control loops



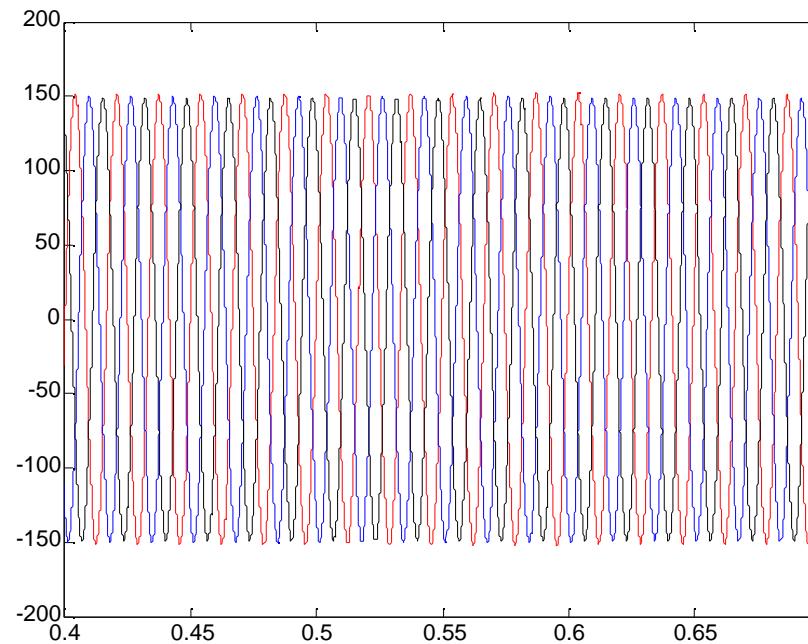
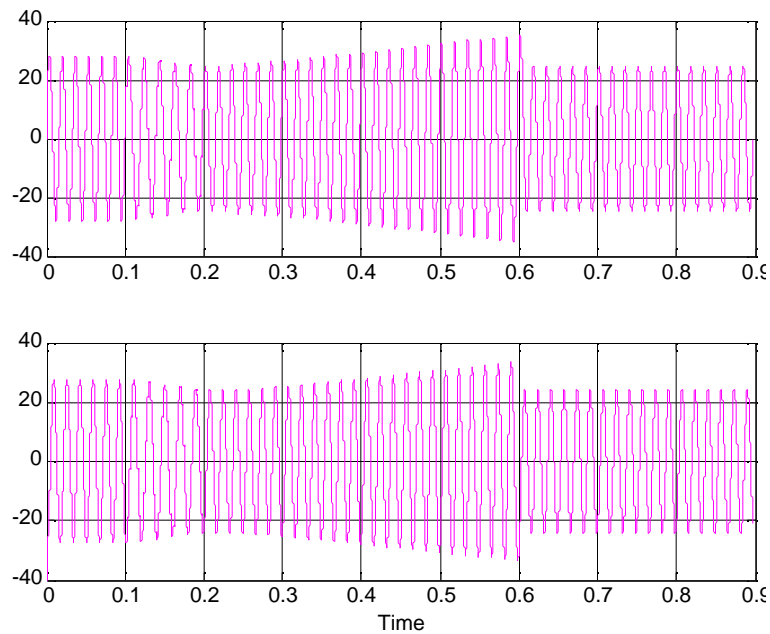
# Reconnection and Islanding



# Voltage during reconnection

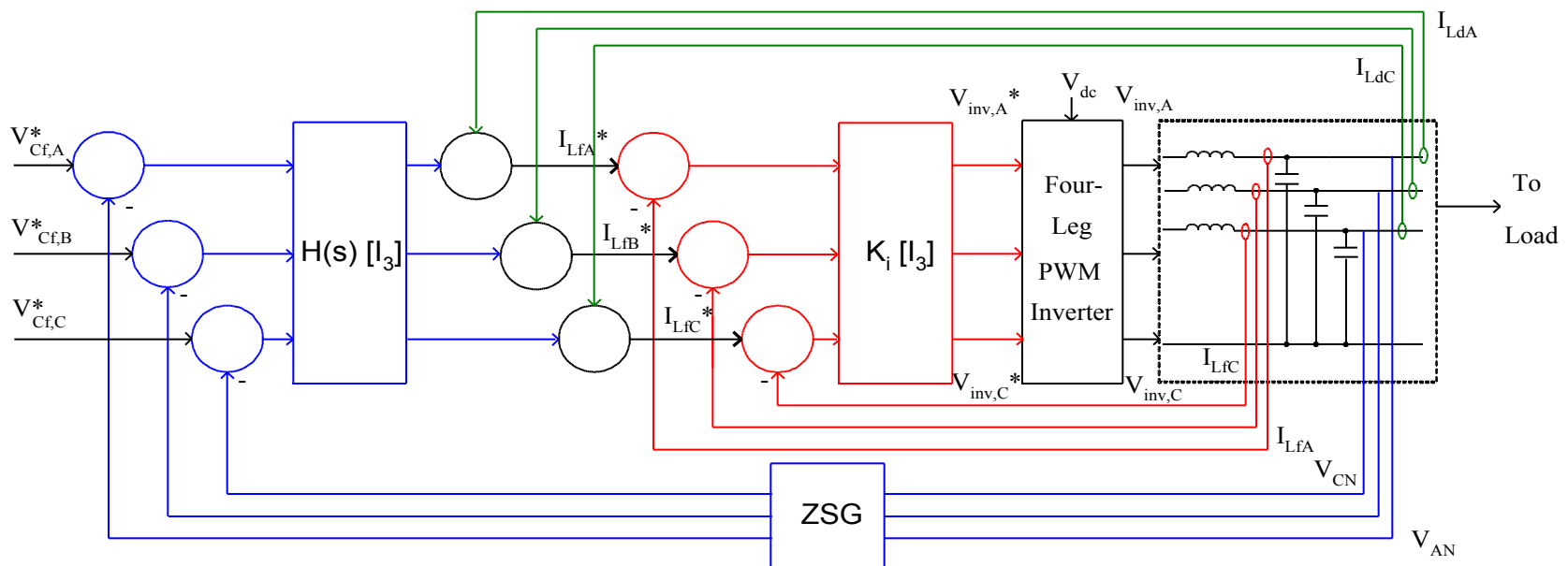


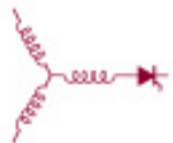
# Voltage during islanding





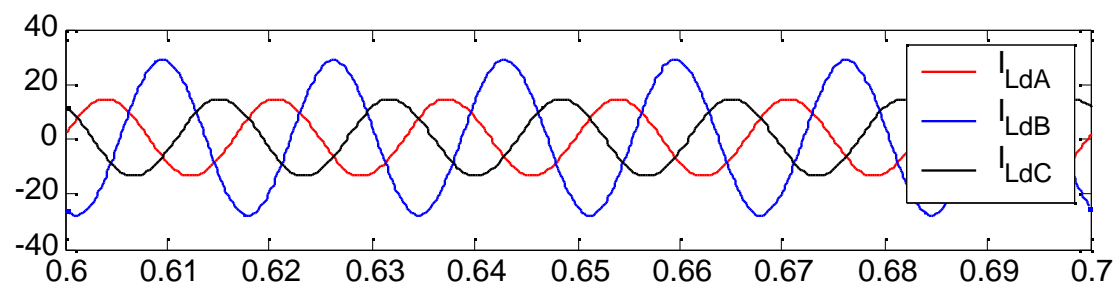
# 4 Wire Inverter Internal Control

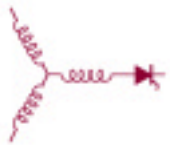




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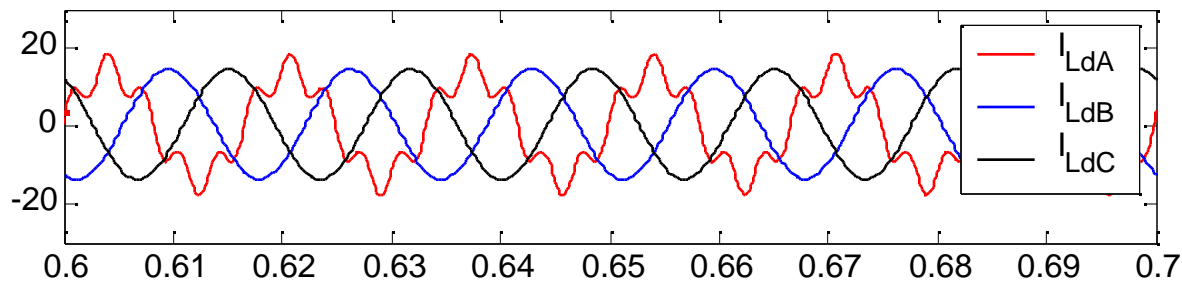
# 4W Inverter Operation with Imbalance





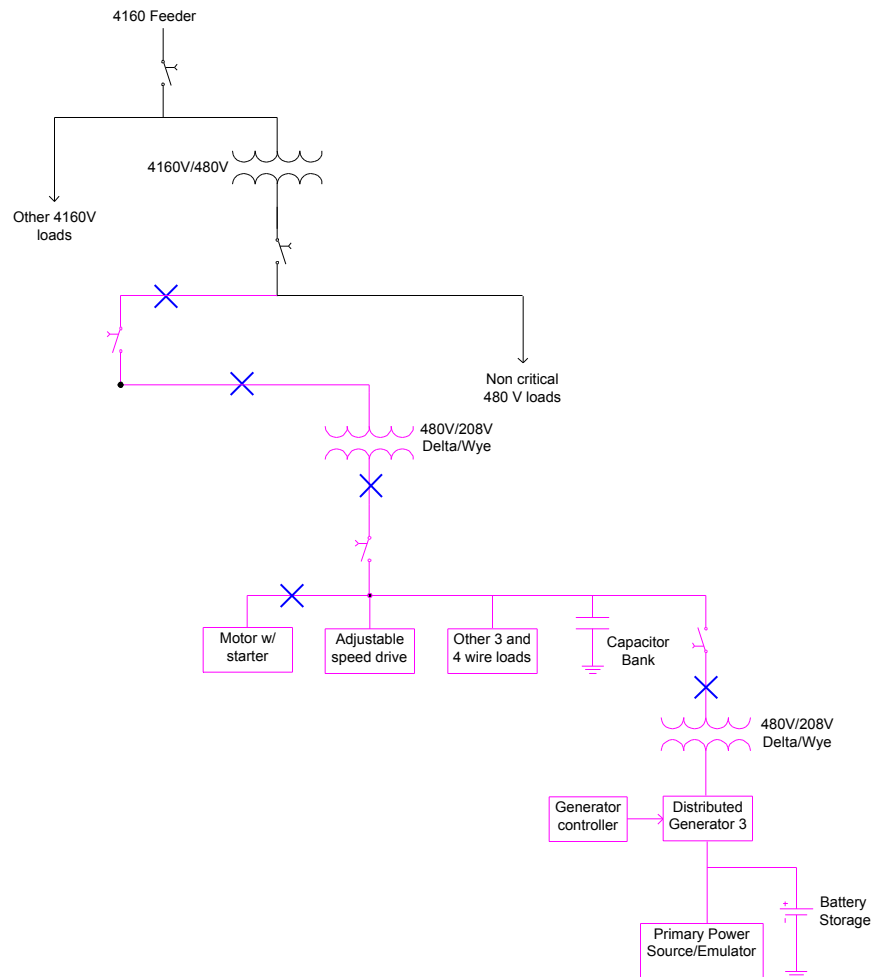
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# 4 Wire Inverter Operation with 1 phase non-linear load



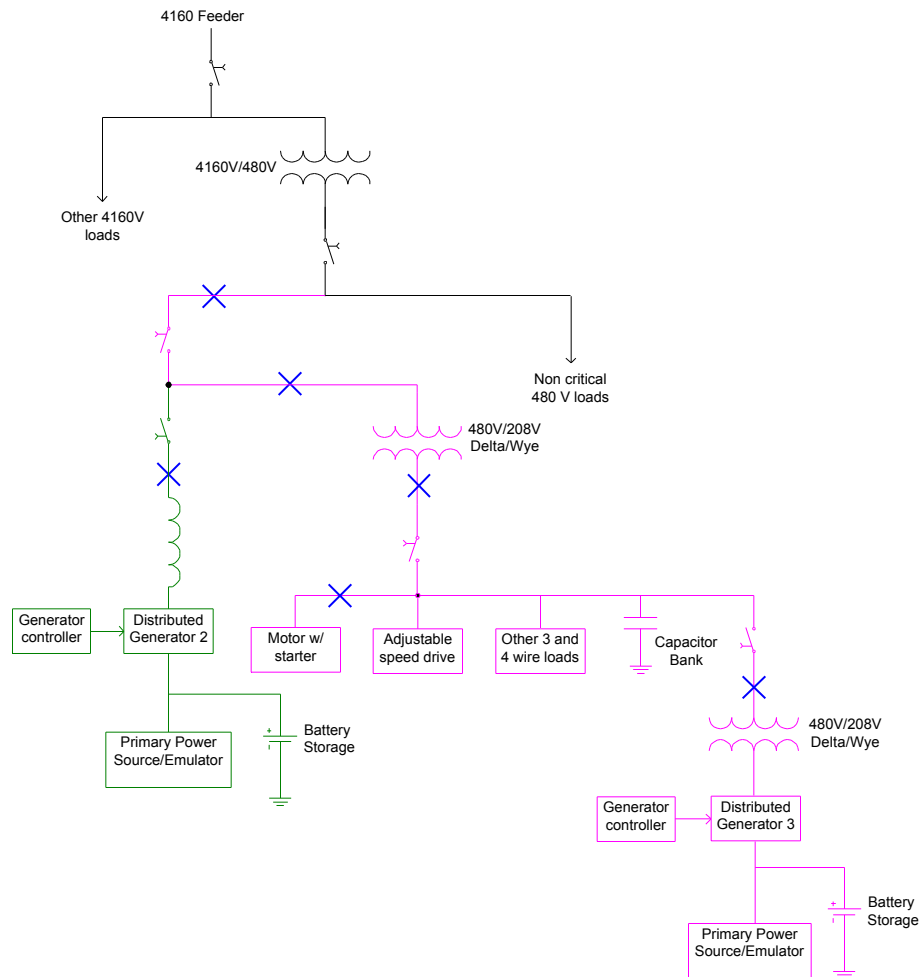
# Evolution of Platform (Year 1)

- Single inverter
- Complex set of loads



# Evolution of Platform (Year 2)

- Two inverters
- Islanding and reconnection
- Correcting power quality events (balanced)



# Evolution of Platform (Year 3)

- Three inverters
- Decentralized control
- Single phase power quality events
- Fault management

